STUDY ON THE GROUNDWATER POTENTIAL EVALUATION AND MANAGEMENT PLAN FOR THE SOUTHEAST KALAHARI (STAMPRIET) ARTESIAN BASIN IN THE REPUBLIC OF NAMIBIA

Japan International Cooperation Agency

Pacific Consultants International

BOREHOLE FINAL REPORT

Borehole

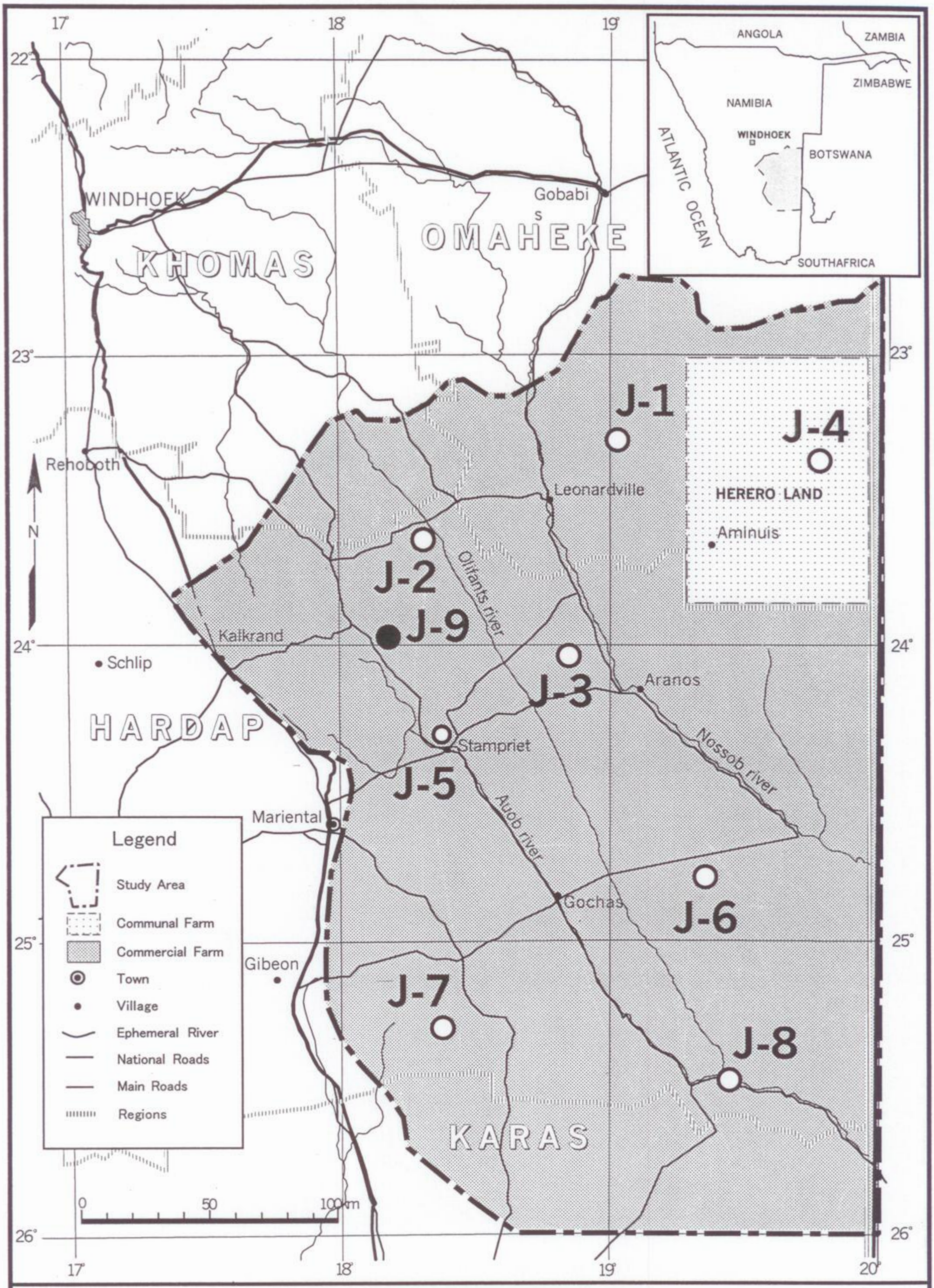
J9-A (WW 39857)

Klein Swartmodder R 135

METZGER PM DRILLING
P.O.Box 11733
Windhoek
Namibia

Windhoek

October 2000



Location Map of Test Boreholes

THE STUDY ON THE GROUNDWATER IN THE STAMPRIET ARTESIAN BASIN	JICA

Contents per Chapter

1. Geological Borehole Log

GEOLOGICAL BOREHOLE LOG

Farm Klein Swartmodder — **WW 39857**
Jica Reference: J 9 A — **S 24, 00125°**
Date completed: 16 August 2000 — **E 18, 21638°**
Collar elev.:

Depth below surface (m)	Section (m)	Lithology	Stratigraphy
0 – 0,5	0,5	Weathered, calcretized **basalt** with shallow sand cover.	**KALKRAND BASALT**
0,5 - 5	4,5	Weathered **basalt**. Colour grey. Chips calcareous. Soft, drilling fast. Remnants of amygdales filled with calcite. (e.g. at 4 m)	
5 - 11	6	Greyish brown to greenish brown, highly weathered **basalt**. Calcareous. **Aquifer**.	
11 - 18	7	Dark greenish grey fresh **basalt**. CO_2 generated in acid, probably due to presence of calcic plagioclase. Generally micro- crystalline.	
18 - 20	2	Purplish fine-crystalline **amygdaloidal basalt**. Amygdales filled by white zeolites (= natrolite ?)	
20 – 35	15	Purplish grey **basalt** with regular disseminated predominantly green olivines. Radial white natrolite fragments and calcite at 23 m and 25m. Black glassy inclusions (tachylite ?) at 30 m.	
35 – 51	16	Greenish grey fine-grained **basalt**.	
51 - 55	4	Grey (to light greenish-grey) **amygdaloidal basalt**. Amygdales filled by predominantly white zeolite (natrolite ?)	
55 - 65	10	Greenish grey fine-crystalline **basalt**.	
65 – 65,5	0,5	Brownish to light purplish **amygdaloidal basalt**. Amygdales small (∅ - 1 mm) and filled with natrolite (?).	
65,5 - 66	0,5	Light reddish baked medium to fine grained sandstone / **quartzite**.	**AUOB (RIETMOND) *****
66 - 92	26	Light reddish to orange, predominantly medium grained, but with coarse grained horizons well sorted **sandstone**. Porous. Grains rounded.	
92 - 140	48	Light reddish to orange, predominantly medium-grained sandstone with coarse-grained horizons. Sandstone well sorted with rounded grains and very porous. Friable. Sandstone mostly massive, but with horizons exhibiting well developed bedding.	**AUOB**
140 – 142 EOH	2	Basement: Pale yellowish fine to very fine crystalline matrix carrying small angular fragments of quartz: rhyolite (?)	**BASEMENT (MARIENHOF FORMATION ?)**

Remarks:

1. The drilling method employed was air-rotary.
2. Based on presence of amygdales in the basalt, together with penetration rates recorded, the basalt can be divided into three flow-cycles: The first cycle would be

from 53 m downwards, the second cycle from 18 to 53 m and the third flow from surface to 18 m.

3. The sandstone can be sub-divided, based on evidence of the caliper- and density-log. From 65,5 m to 92 m only minimal washout took place. In this horizon the density was also approximately 2,5 g/cc to 2,8 g/cc, compared to a variation of between 1,75 and 2,1 g/cc in the sandstone below 92 m. This indicates a slightly more effective cementation of the upper sequence of the sandstone. As Rietmond sandstone was described elsewhere on this farm, this upper portion could in this case also be classified as Rietmond Member.
4. Less than 1 m of the very hard un-weathered basement (= rhyolite?) was penetrated. Accute danger of collapse of the upper friable sandstone prohibited any further drilling in an un-cased borehole. Continuous washout of the friable sandstone occurs while drilling in this hard basement.
5. The sandstone was gravel-packed to prevent collapse during pumping.
6. Cement grout was emplaced by means of tremie pipe.

This borehole was logged by F. Bockmuhl.

2. Penetration Record

	Penetration Record Borehole J 9 N WW 39857				
Depth (m)	Pen. Rate (min/m)	Time	Date	Remarks	
0			12/08/00		
5	1.6				
	1.8				
	2.45				
	1.7				
	1.2				
10	1.35				
	1.25				
	3.45				
	9.75				
	8.5				
	6.2				
	8.4				
	9.45				
	5.8				
20	5.85				
	6.2				
	8.5				
	12.75	07:45	13/08/00		
	11.8				
	11.85				
	13.65				
	14.9				
	13.8				
	10.35				
30	8.3				
	10.1				
	8.05				
	6.75				
	6.75				
	0.85				
	8.2				
	4.05				
	5.75				
	10.7				
40	14.05				
	13.5				
	8.9				
	4.85				
	6.75				
	8.5				
	7.2				
	7.1				
	4.7				
	4.8				
50	3.9				
	4.75				
	3.9				

	6.35				
	8.85				
	15.1				
	22.2				
	19.4				
	27.95				
	22.45				
60	13.1				
	11.8				
	10.25				
	9.6				
	10.65				
	2.7				
	0.5				
	0.25				
	0.7				
	0.8				
70	1.2				
	1.2				
	1.15				
	1.7				
	1.15				
	0.8				
	0.75				
	0.65				
	0.65				
	0.9				
80	0.4				
	0.65				
	0.6				
	1.1				
	1				
	1.15				
	1.15				
	0.95				
	0.95				
	1				
90	0.95				
	0.85				
	0.5				
	0.42				
	1.3				
	1.4				
	0.75				
	1				
	1.85				
	1.65				
100	1.2				
	1.5				
	1.15				
	1.35				
	1.1				
	1.2				
	0.9				
	0.55				

110	1.2				
	1.05				
	1.4				
	1.1				
	1.55				
	1				
	0.5				
	0.85				
	0.55				
	0.65				
120	0.7				
	0.4				
	0.35				
	0.4				
	0.6				
	0.3				
130	0.6				
	0.9				
	0.9				
	1.6				
	1.8				
	8.1				
	1.65			E.C 1143 micro S/cm	
	2.2			pH 7,99	
	3.2				
	2.25				
140	1.9				
	5.7				
	19			meter not completely penetrated	

J9npen

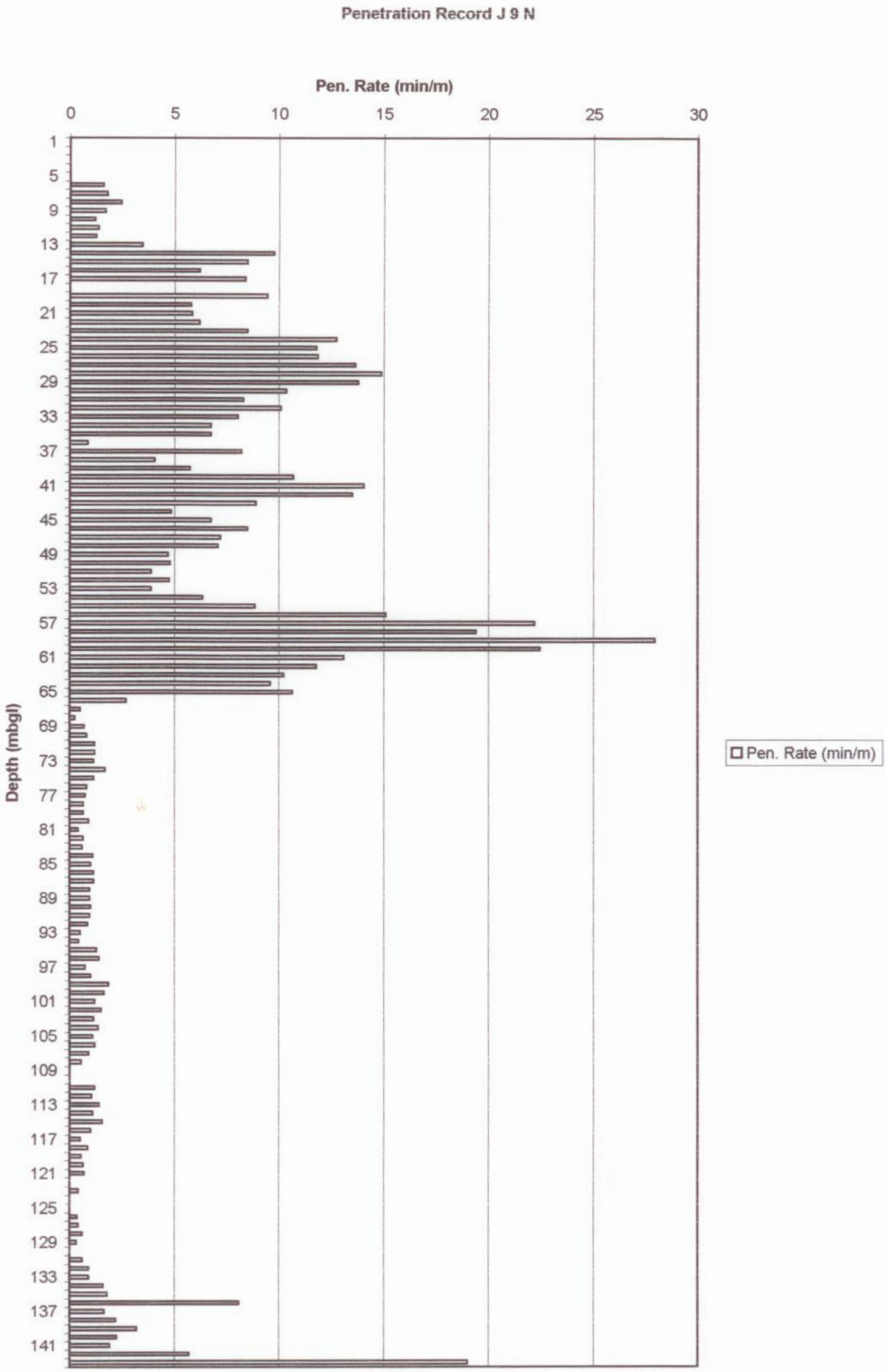


Chart1

J9npen

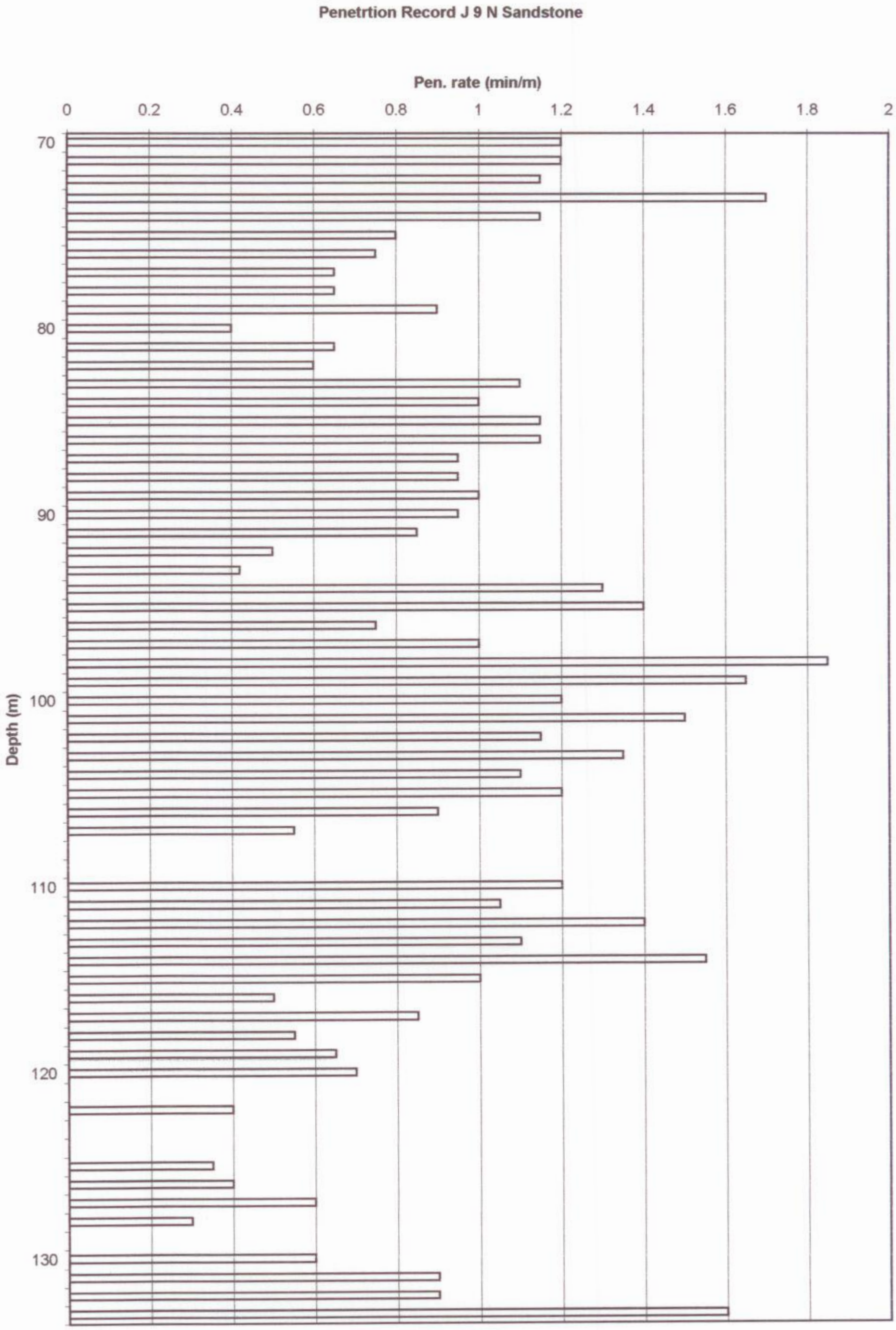


Chart3

3. Mud Rotary Drilling Log

THE STUDY ON THE GROUNDWATER POTENTIAL EVALUATION AND MANAGEMENT PLAN IN THE SOUTHEAST KALAHARI (STAMPRIET) ARTESIAN BASIN

MUD ROTARY DRILLING LOG

JICA REFERENCE: J 9 A LOCALITY: Klein Swartmodder R 135 WW 39857 DATE: August 2000

REMARKS: This borehole was drilled by the air-rotary method only, with minimal chemical addition to the drill fluid, relative to the amount of water delivered during drilling. Viscosity tests were therefore not conducted during drilling operations.
At the final depth, before logging, inorder to prevent collapse, this borehole was filled with a rather viscose mud. The representative data are tabulated below.

TIME	DEPTH mbgl	MARSH FUNNEL TEST 1000 ml	MARSH FUNNEL TEST 500 ml	E. C. µS/cm	DENSITY	pH	TEMPERATURE ° C	COMMENT
15:00	*143*	*40*	*21*	*1143*		*7.99*	*27.3*	*Data recorded before logging.*

Only one step of logging took place.

4. Geophysical Log and Casing Design

5. Borehole Development Data

THE STUDY ON THE GROUNDWATER POTENTIAL EVALUATION AND MANAGEMENT PLAN IN THE SOUTHEAST KALAHARI (STAMPRIET) ARTESIAN BASIN

BOREHOLE DEVELOPMENT DATA

JICA REFERENCE: J 9 A LOCALITY: Klein Swartmodder R 135 WW 39857 DATE: 23/08/00 (starting)

TIME (actual)	P.I.D. (mbsu)	½ 90° V-Notch (mm)	Yield (m^3/h)	E.C. (mS/m)	Water Level (mbsu)	Remarks
18:00				127		Date 23/08/00
19:00	132.5	120	12.6		3.04	
20:00	131.5	115				
21:00	130.5	110				
22:00	129.5					
23:00	128.5					
24:00	127.5	110	10.08	126	2.85	Stop until next day
07:00	126.5	110	10.08			Date 24/08/00: At 1 hourly intervals the pipes and surger are lifted, 1 m at a time. This is done until 13:00 when PID is 121.5 m
13:45	120.5	140	> 20	112	3.20	Surger is lifted at intervals of 30 minutes, until a depth of 115.5 m is reached
17:15	114.5	140	>20	103	3.40	Surger lifted in 30 minute cycle until depth of 109.5 m is reached at 20:15. Stop for the day.
07:00	108.5	130	18.72	104	3.20	Date 25/08/00. Surger slowly retrieved.
11:00	102.5	140	>20	103	3.2	Surger slowly moved up-hole.
13:20	96.5	150	>>20	103	3.8	Surger slowly retrieved. Stop for the day at 16:20.
06:30	90.5	110	10.08	104	3.2	Date 26/08/00. Surger slowly retrieved.
10:00	84.5	150	>>20		3.8	Surger slowly retrieved.
12:30	78.5	150	>>20	103	3.70	Surger slowly retrieved.

TIME (actual)	P.I.D. (mbsu)	½ 90° V-Notch (mm)	Yield (m^3/h)	E.C. (mS/m)	Water Level (mbsu)	Remarks
07:00	72.5	155	>>20	104	3.8	Date 27/08/00. Surger slowly retrieved.
12:15	64.5					Reached top part of screens. All screens properly developed and fines removed. Lower open ended pipes again to bottom of hole. Clean out sump.
16:00						Work completed.

Remarks:

1. By using a surger water is forced to enter screens through the gravel pack at a localized and controlled horizon only. Developing takes place optimally.
2. Yield recorded therefore is only representative of the one meter directly opposite the surger.
3. This borehole was developed by cable tool rig for 11.5 hours prior to airlift develpement.
4. Finally development was also done by submersible pump on28/08/00. Data tabulated below.

TIME (actual)	Pump time (min)	Water Level (mbsu)	Yield (m^3/h)	E.C. (mS/m)	Remarks
18:20	1	5.68	48.00	103.2	
	2	5.82			
	3	5.60			
	4	5.82	12.00		
	5	5.60			
	6	4.62			
	7	3.75	12.504		
	8	3.74			

TIME (actual)	Pump time (min)	Water Level (mbsu)	Yield (m^3/h)	E.C. (mS/m)	Remarks
	9	3.74			
	10	3.72			
	12			103.4	
	14				
	16				
	18				
	20	3.72	12.46		
	23	3.73			
	26	3.96			
	30	4.01	14.58		
	35	4.05			
19:00	40	4.06			
	43	4.77			
	45	4.81	31.55		
	50	4.82			
	55	4.81			
	60	6.02	47.65	102.8	
	65				
	66	6.02			
	67				
	68				
	69	6.02	2.8		
	70				
	75				
	80	6.02			
	85	6.04		102.6	
	90				

TIME (actual)	Pump time (min)	Water Level (mbsu)	Yield (m^3/h)	E.C. (mS/m)	Remarks
	95	6.06			
20:00	100	6.06			Stop exercise as pump is at maximum and draw down is only minimal.

6. Evaluation of Pumping Test

1. PUMPING TEST ANALYSIS

J9-A (WW39857) - Pumping well (sub-artesian)

J9 (WW31759) - Observation well (sub-artesian)

J9 (WW245) - Observation well (artesian)

1.1. Well Efficiency (Step Drawdown Test) (Annex 1)

Well Efficiency was analysed by making use of the Jacob method for draw down data. Aquifer parameters used for the calculation of well efficiency were obtained from the evaluation results of the constant discharge test, which is discussed in **Section 1.2** below.

The well efficiencies at the range of pumping rates used during the step drawdown test are summarised in **Table 1** below.

Table 1: J9-A; borehole efficiency at various pumping rates

Borehole number	Step	Abstraction Rate [m^3/h]	Draw Down* [m]	Borehole Efficiency [%]
J9-A	1	15	0.59	85.9
	2	25	0.39	64.8
	3	35	1.14	52.1
	4	45	2.72	43.5

* at cut-off time Δt, after which well bore storage has no affect on the well performance

Data on the linear and non-linear well losses and skin factors as well as the efficient well radius are presented in **Annex 1.**

1.2. Constant Discharge Test Analysis (Annex 2 - 6)

An abstraction rate of 46 m^3/h was applied for the constant discharge test. The constant discharge draw down curve of abstraction borehole **J9-A** indicates confined conditions. For confined aquifers, the Theis analysis method with draw down and recovery data was used to calculate the hydraulic conductivity of the aquifer (**Annex 2 & 3**). The recovery data shows higher transmissivity values. In addition the transmissivity and storativity was calculated from the draw down curve of the observation borehole WW31759 (**Annex 4**). The observation borehole was affected by the pumping from **J9-A** and showed a draw down of approximately 20 cm after 3-days pumping (**Annex 5**). Again, the transmissivity was higher than the evaluated values of the pumping borehole, indicating some increase in transmissivity away from **J9-A**. The order of magnitude, however, is the same in all cases.

The additional pumping from the farm borehole WW245, which penetrates the same aquifer, most probably influenced the draw down curve of WW31759.

The results of the constant discharge analysis are summarised in **Table 2** below.

Table 2: Aquifer Parameters calculated for J9-A; Auob sandstone

Borehole number	Analysis Method	T [m^2/day]	s [m]	k_f [cm/sec]	S [-]	Simulation model
J9-A	Theis-draw down	1,240	75	1.9×10^{-2}	*5×10^{-5}	Theis
	Theis-recovery	1,640	75	2.5×10^{-2}	*5×10^{-5}	
	Theis-draw down Obs. BH WW31759	2,160			3×10^{-4}	

*estimated

The Theis model for confined aquifer conditions was used to simulate and verify the actual data and analysis approach of the constant discharge test. No leaky conditions could be evaluated for **J9-A**. Simulation parameters summarised in **Table 2** were used in simulation of the actual pumping test data (See **Annex 5** for simulation results).

Annex 6 compares the draw down results of the pumping borehole **J9-A** and observation borehole WW31759.

The radius of influence (R) was estimated after SICHARDT (1928) using the equation:

$R = 3000 \times s \times K_f^{1/2}$

$R = 3000 \times 2.84 \times 0.018 = \underline{156\ m}$

where

R = Radius of influence

s = Draw down in abstraction borehole at end of pumping

K_f = Permeability of the aquifer

The equation is approximately correct for unconfined aquifers. In case of a confined aquifer the radius of influence is larger and the 156 m are considered to be the minimum value.

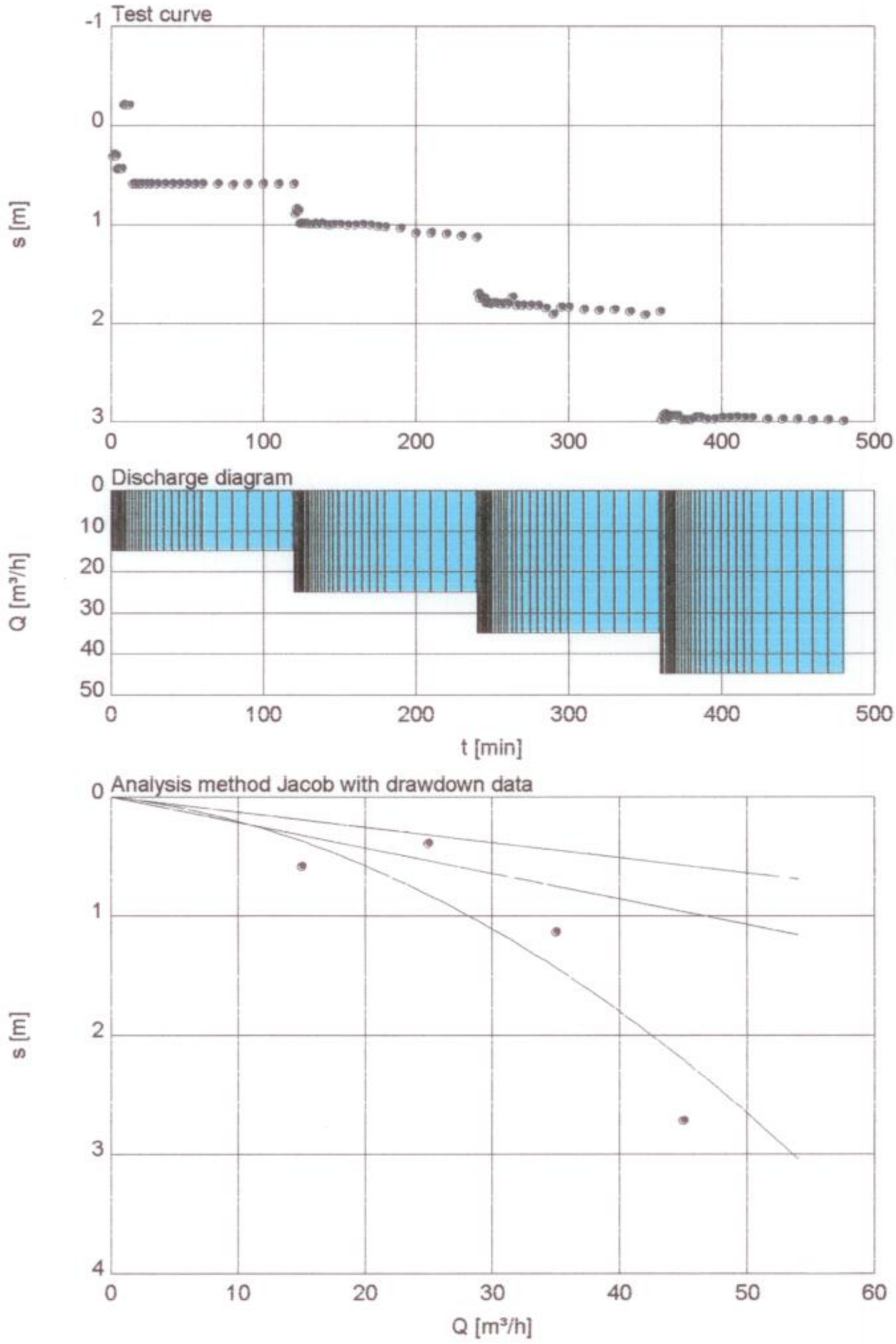
The reaction of the water level in observation borehole WW31759 shows that the actual radius of influence is much lager than the above estimate. R is estimated to be greater than 500 m.

Groundwater Study in the Stampriet Artesian Basin

Evaluation of Test Pumping Data

Step test analysis

Pumped well J9_A



Borehole, well & aquifer

Drilled:	08/00
Latitude:	24.00125
Longitude:	18.21638
Elevation:	1209 [m]
Depth:	142 [m]
Stick up:	0.70 [m]
Bh. radius:	0.100 [m]
Casing radius:	0.076 [m]
RWL:	3.22 [m]
max.drawdown:	2.99 [m]
Aq.type:	confined
Aq.thickness:	75.00 [m]
Stratigraphy:	Auob
Lithology:	Sandstone

Test running

Start:29/08/2000 11:00:00	
Dis.dur.:	480 [min]
Av.dis.:	30 [m³/h]
Max.dis.:	45 [m³/h]
Min.dis.:	15 [m³/h]
Total dis.:	240 [m³]
Crew:	Metzger_PM
Supervisor:	PCI

Results

Well performance:

s: (B1+B2)*Q+C*Q²

Linear aquifer loss B1:	2.1E-2
Linear well loss B2:	-8.6E-03
Non-linear well loss C:	8.1E-4

	Q [m³/h]	s [m]	Eff [%]
Step 1:	15.0	0.59	85.9
Step 2:	25.0	0.39	64.8
Step 3:	35.0	1.14	52.1
Step 4:	45.0	2.72	43.5

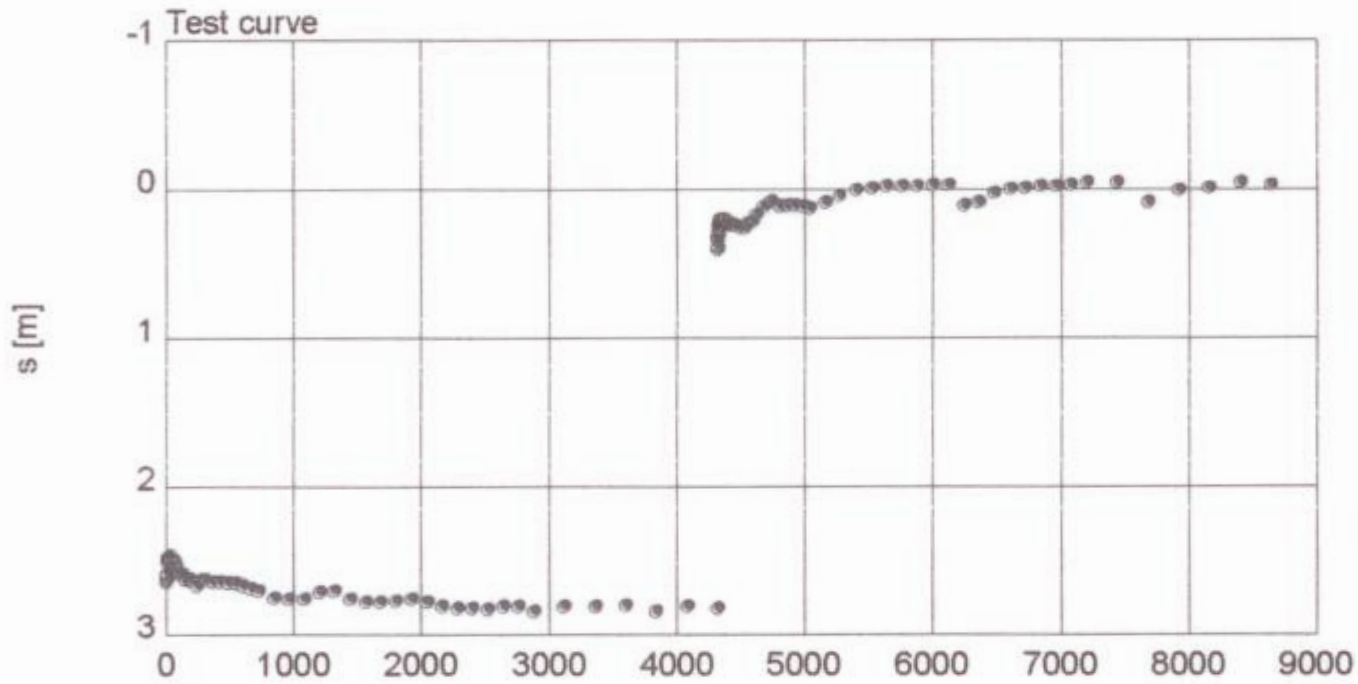
Linear skin factor:	-2.80 [-]
Non-linear skin factor:	6.29 [d/m³]
Effective well radius:	1.2E-5 [m]

Groundwater Study in the Stampriet Artesian Basin

Evaluation of Test Pumping Data

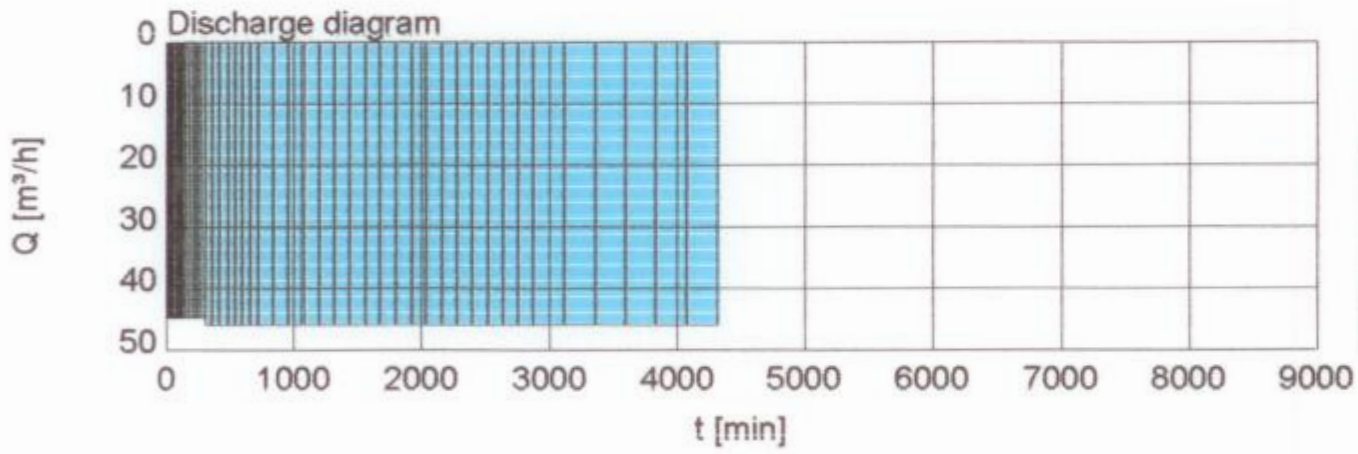
Test pumping analysis

Pumped well J9_A



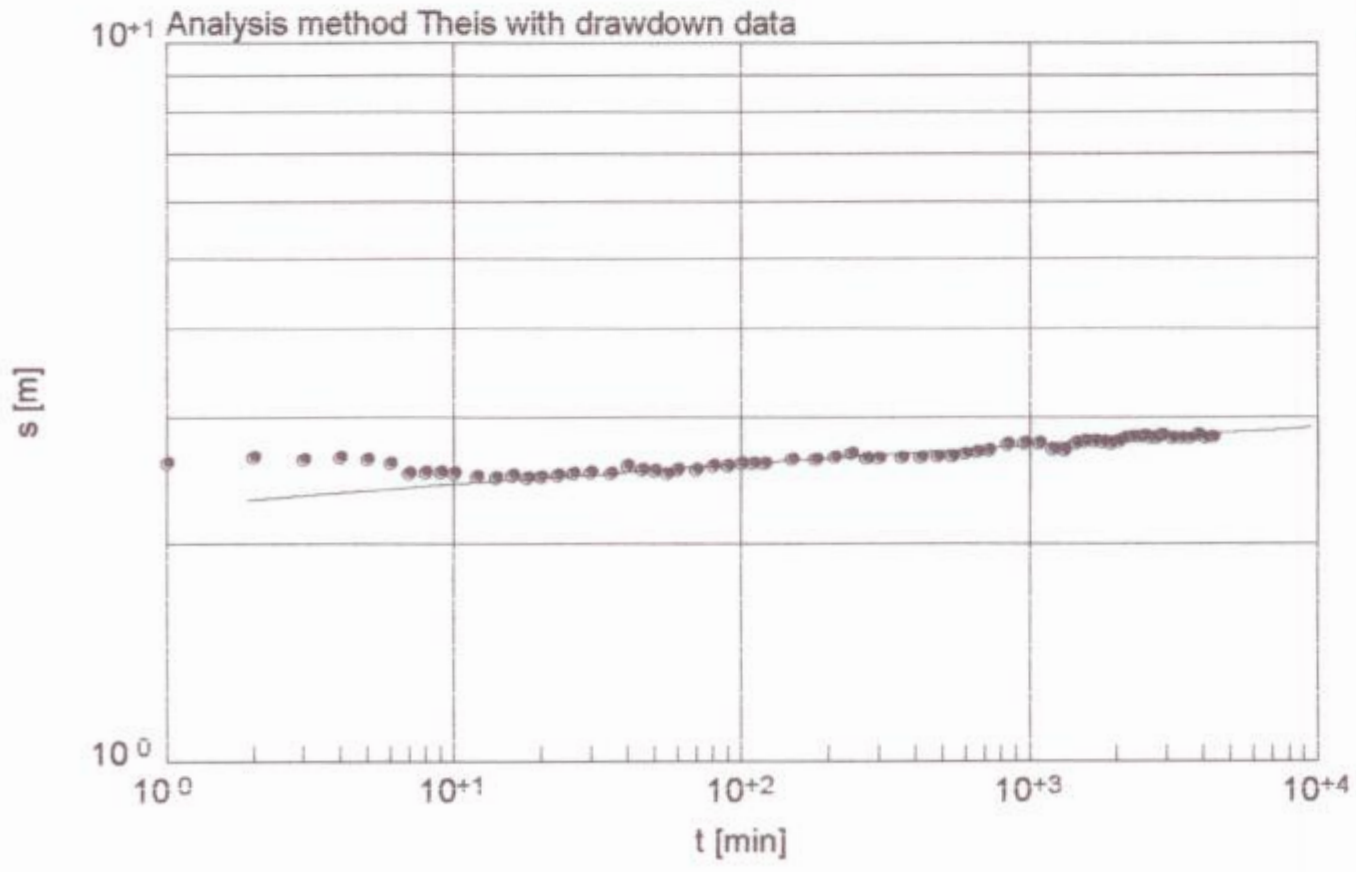
Borehole, well & aquifer

Drilled:	08/00
Latitude:	24.00125
Longitude:	18.21638
Elevation:	1209 [m]
Depth:	142 [m]
Stick up:	0.70 [m]
Bh. radius:	0.100 [m]
Casing radius:	0.076 [m]
RWL:	3.21 [m]
max.drawdown:	2.84 [m]
Aq.type:	confined
Aq.thickness:	75.00 [m]
Stratigraphy:	Auob
Lithology:	Sandstone



Test running

Start:30/08/2000 11:00:00	
Dis.dur.:	4320 [min]
Av.dis.:	46.1 [m³/h]
Max.dis.:	48.4 [m³/h]
Min.dis.:	45 [m³/h]
Total dis.:	3.32E3 [m³]
Crew:	Metzger_PM
Supervisor:	PCI



Results

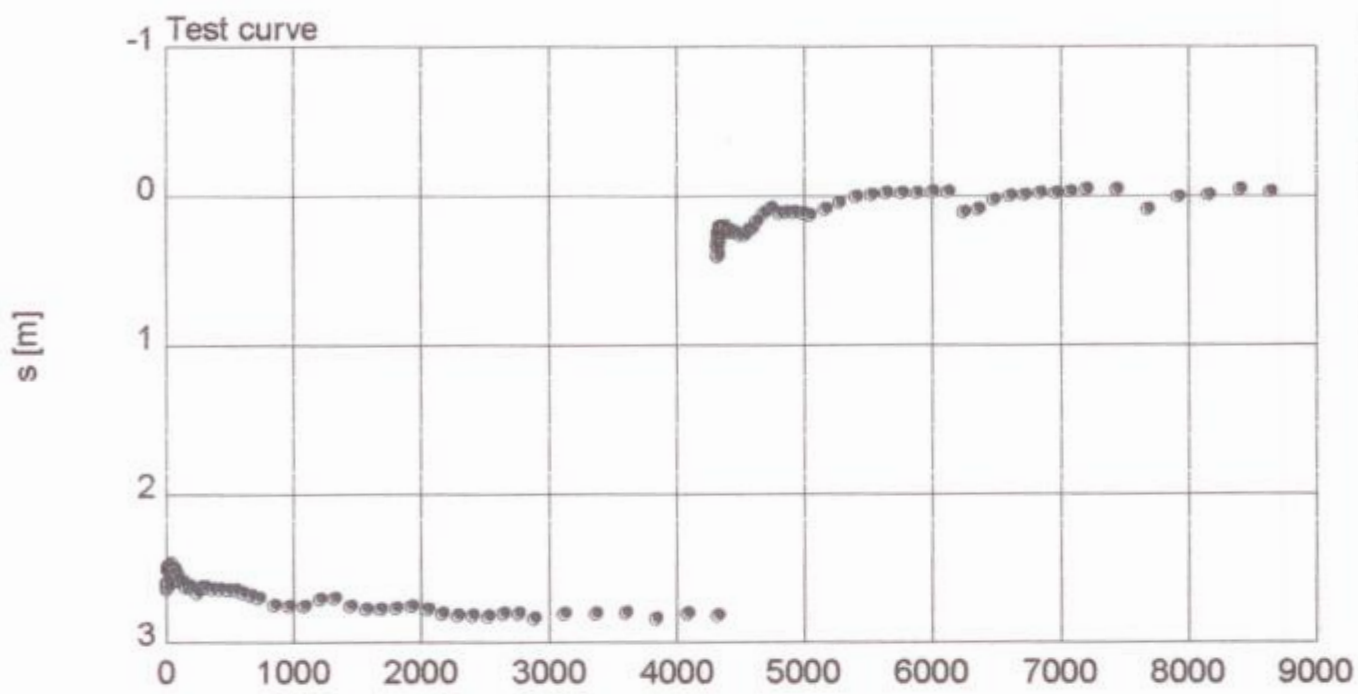
Match parameter:	
Q:	46.1 [m³/h]
t:	92 [min]
s:	2.55 [m]
1/u:	9.67E15 [-]
W(u):	35.8 [-]
Aquifer parameter:	
T:	1.24E3 [m²/d]
k:	16.5 [m/d]

Groundwater Study in the Stampriet Artesian Basin

Evaluation of Test Pumping Data

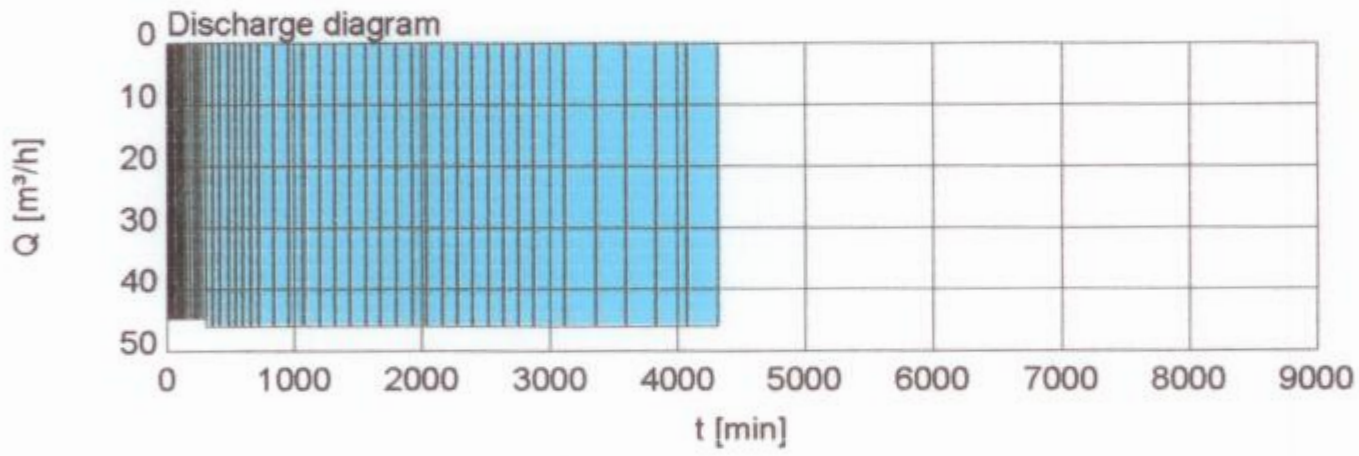
Test pumping analysis

Pumped well J9_A



Borehole, well & aquifer

Drilled:	08/00
Latitude:	24.00125
Longitude:	18.21638
Elevation:	1209 [m]
Depth:	142 [m]
Stick up:	0.70 [m]
Bh. radius:	0.100 [m]
Casing radius:	0.076 [m]
RWL:	3.21 [m]
max.drawdown:	2.84 [m]
Aq.type:	confined
Aq.thickness:	75.00 [m]
Stratigraphy:	Auob
Lithology:	Sandstone



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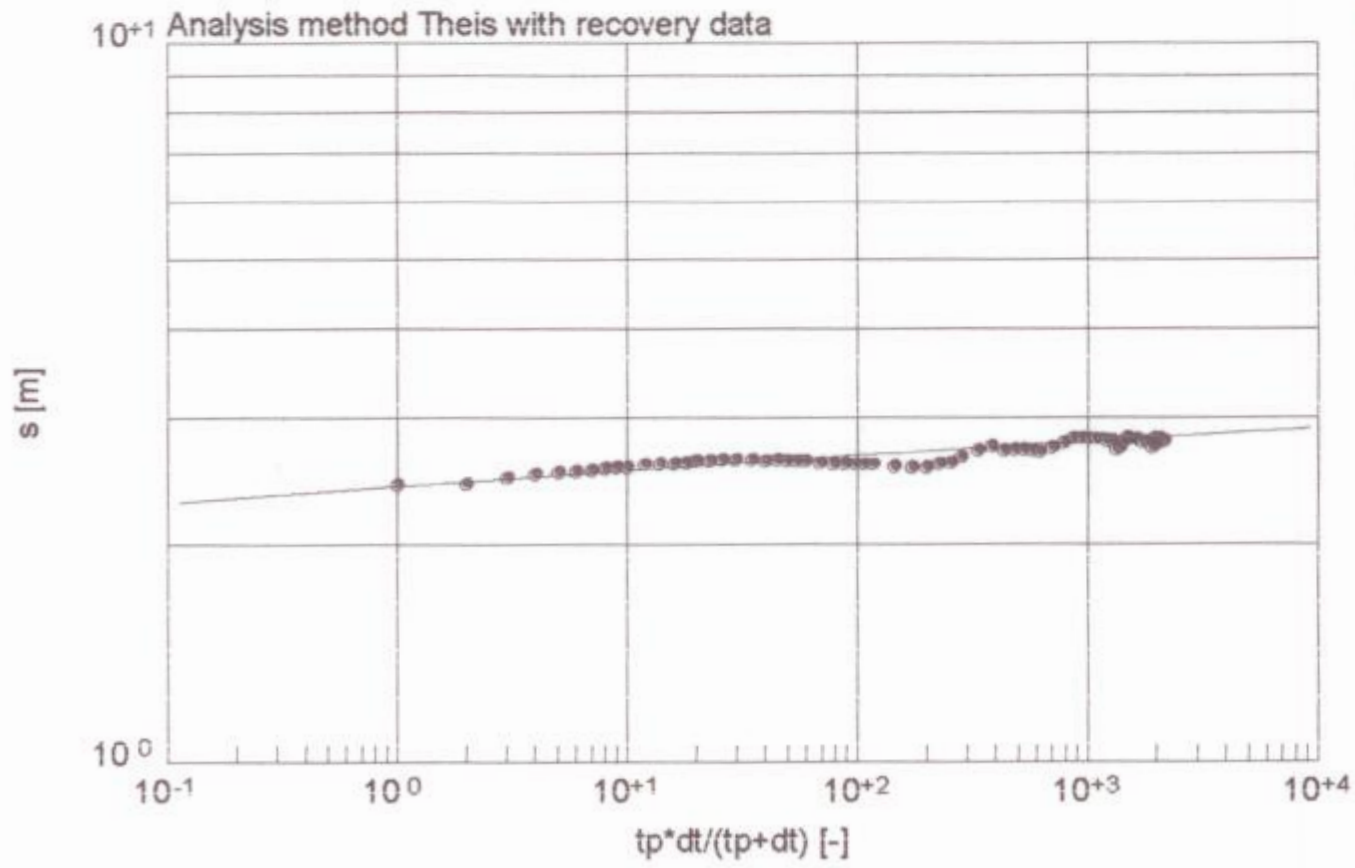


Results

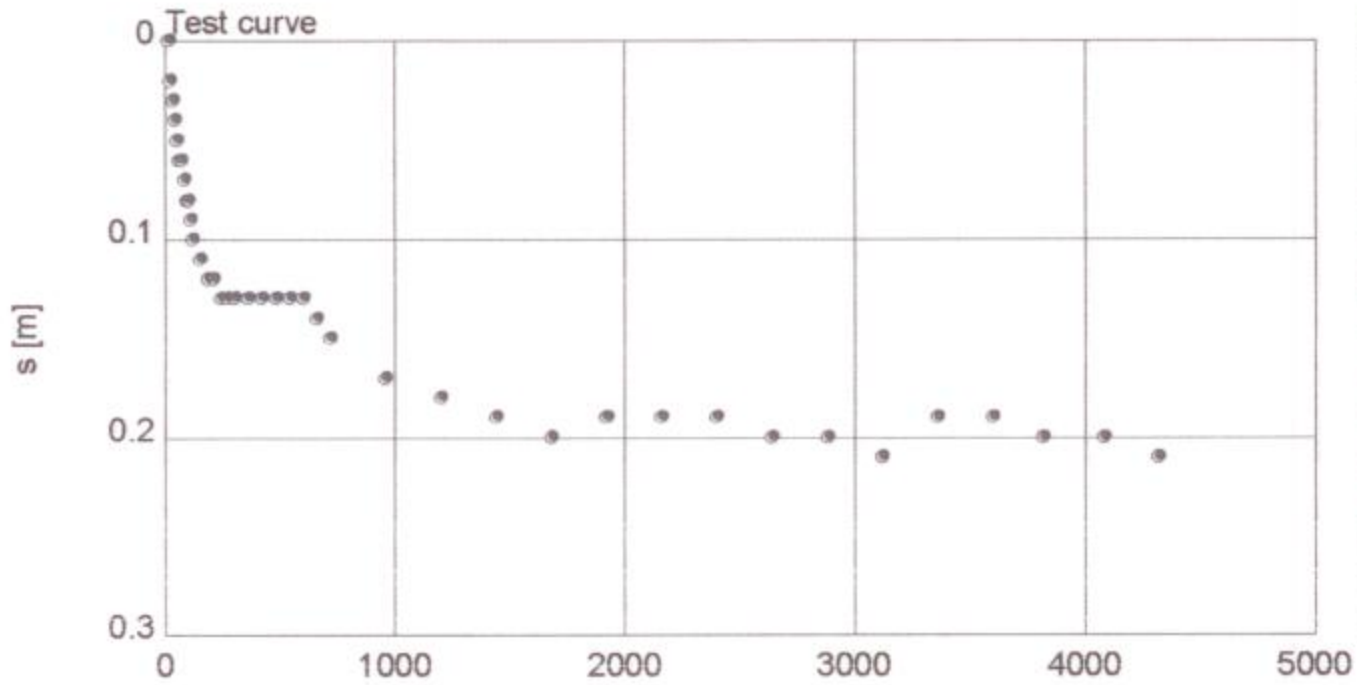
Match parameter:	
Q:	46.1 [m³/h]
t:	624 [min]
s:	2.74 [m]
1/u:	3.37E22 [-]
W(u):	50.9 [-]
Aquifer parameter:	
T:	1.64E3 [m²/d]
k:	21.8 [m/d]
S+sf:	8.4E-18 [-]

Groundwater Study in the Stampriet Artesian Basin

Evaluation of Test Pumping Data

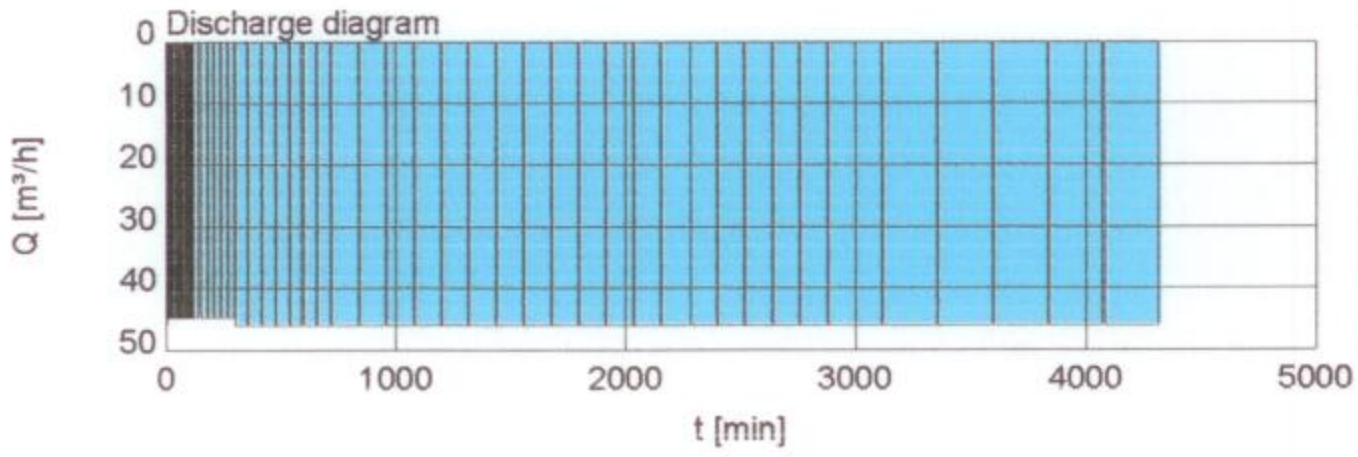
Test pumping analysis

Observation well WW31759



Borehole, well & aquifer

Drilled:	
Latitude:	
Longitude:	
Elevation:	
Depth:	
Stick up:	0.00 [m]
Well distance:	425.00 [m]
RWL:	1.33 [m]
max.drawdown:	0.21 [m]
Aq.type:	dry
Aq.thickness:	0.00 [m]
Stratigraphy:	Auob
Lithology:	Sandstone



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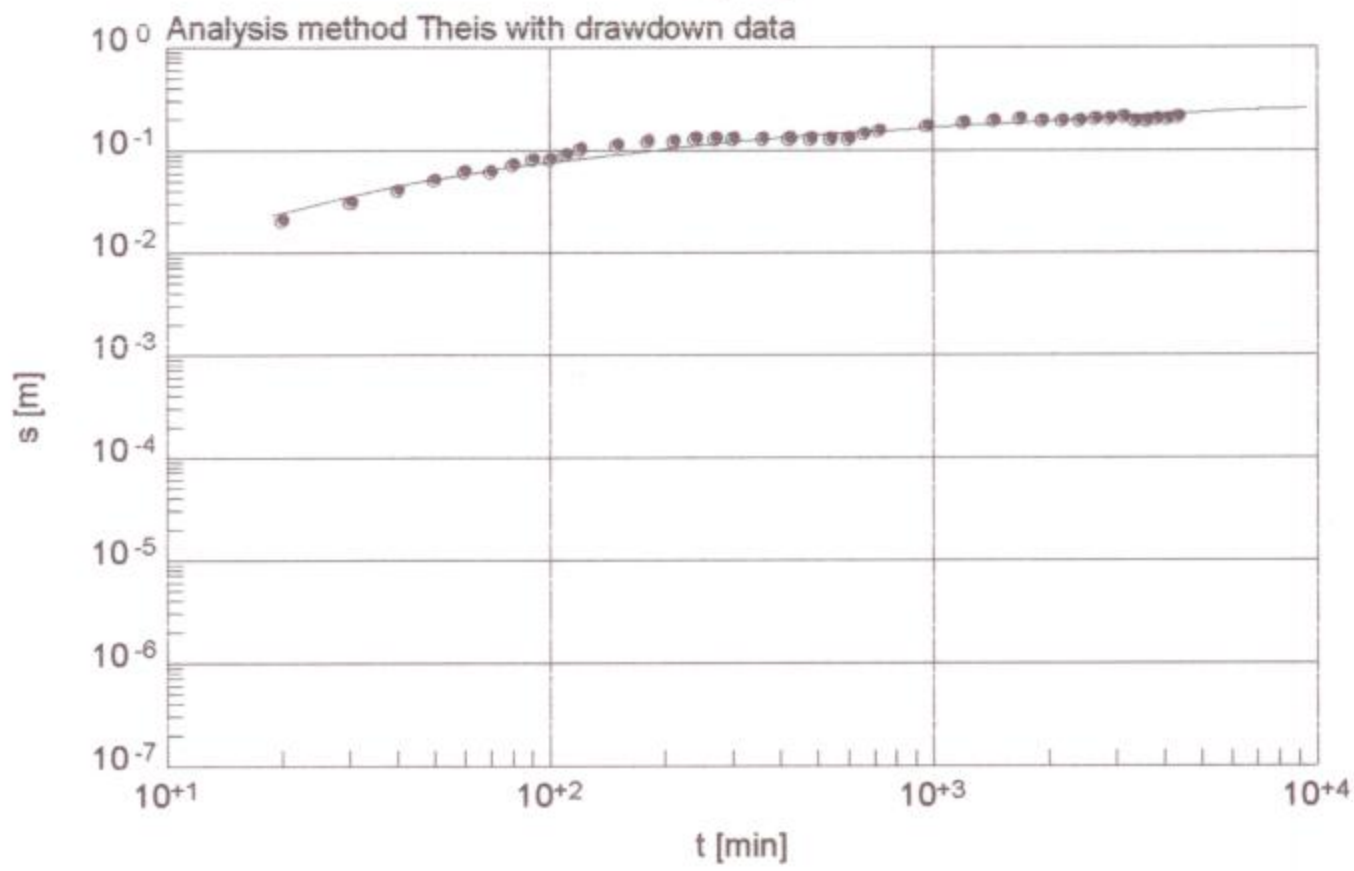
Crew:	Metzger_PM
Supervisor:	PCI



Results

Match parameter:	
Q:	46.1 [m³/h]
t:	158 [min]
s:	0.0891 [m]
1/u:	16.9 [-]
W(u):	2.19 [-]
Aquifer parameter:	
T:	2.16E3 [m²/d]
S:	0.00031 [-]

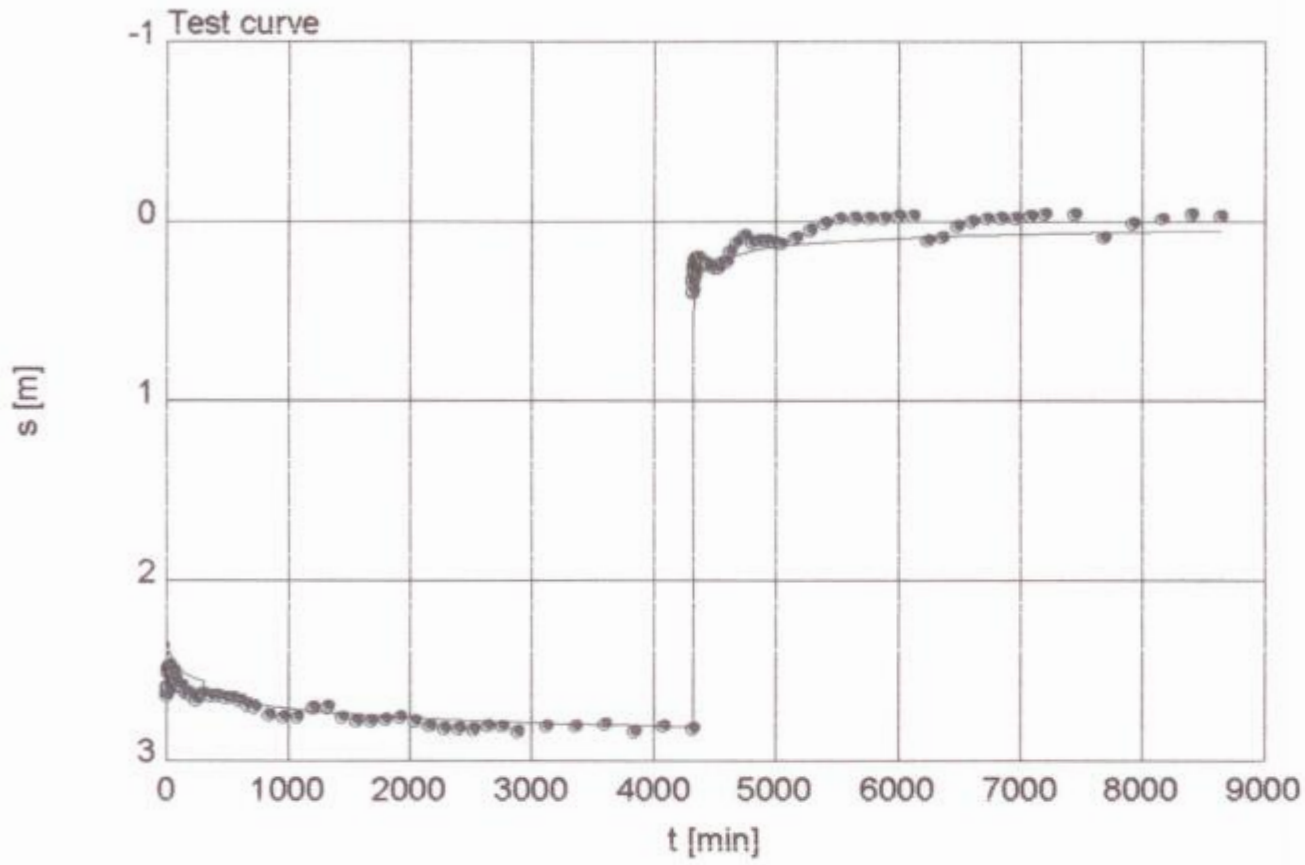
Date 23/10/00	prepared by BIWAC	Annex 4

Groundwater Study in the Stampriet Artesian Basin

Evaluation of Test Pumping Data

Test pumping diagnosis

Pumped well J9_A

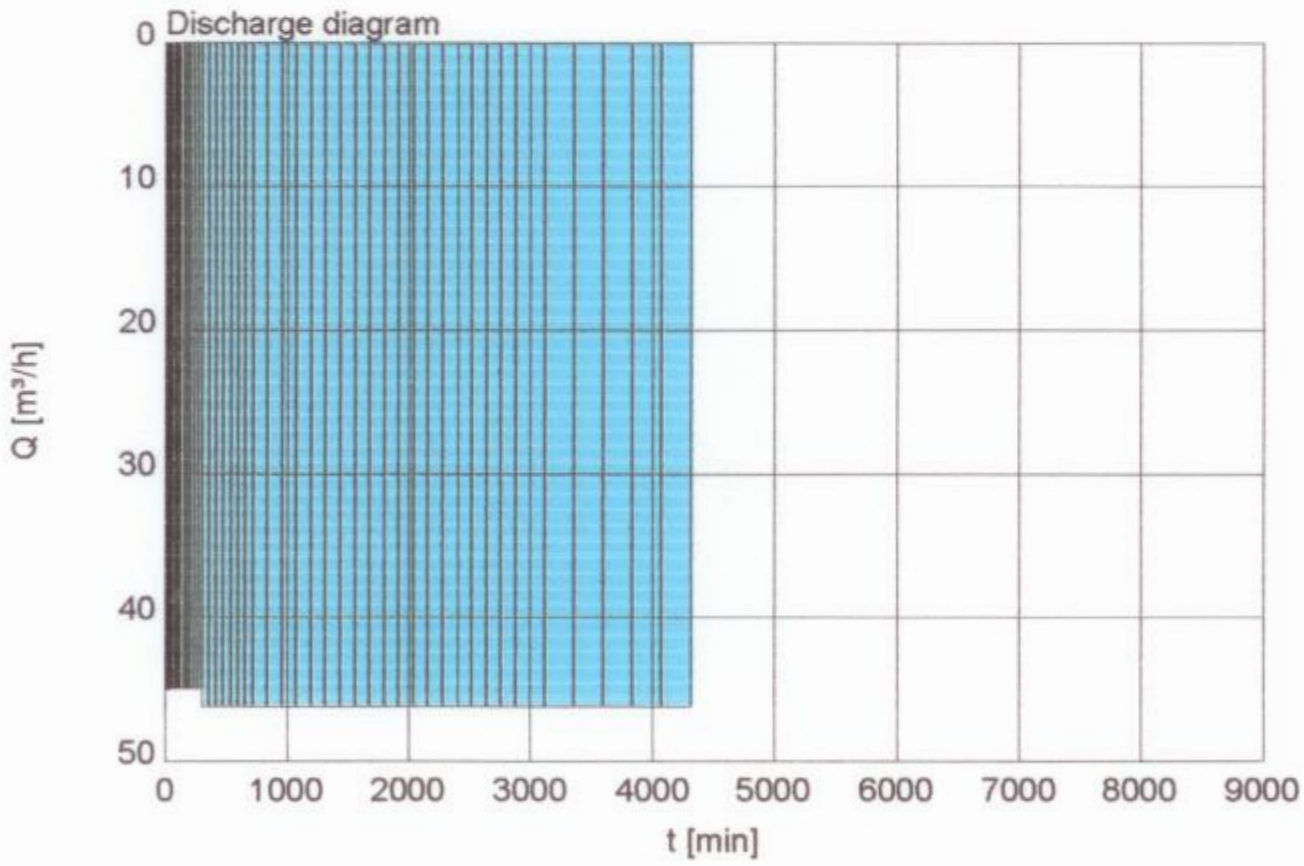


Remarks

Simulated draw down / recovery curve applying the Theis model for confined aquifers.

The simulated curve fits the actual data using the following aquifer parameter:

Confined aquifer
T = 1240 m2/day
S = 0.00005
Linear skin s = 8.0



Discharge info

Dis.dur.:4320 [min]
tcorr: 4312 [min]

Av.dis.: 46.13 [m³/h]
max.dis.:48.38 [m³/h]
min.dis.:45.02 [m³/h]
Qn: 46.21 [m³/h]

Dis.sum: 3322 [m³]

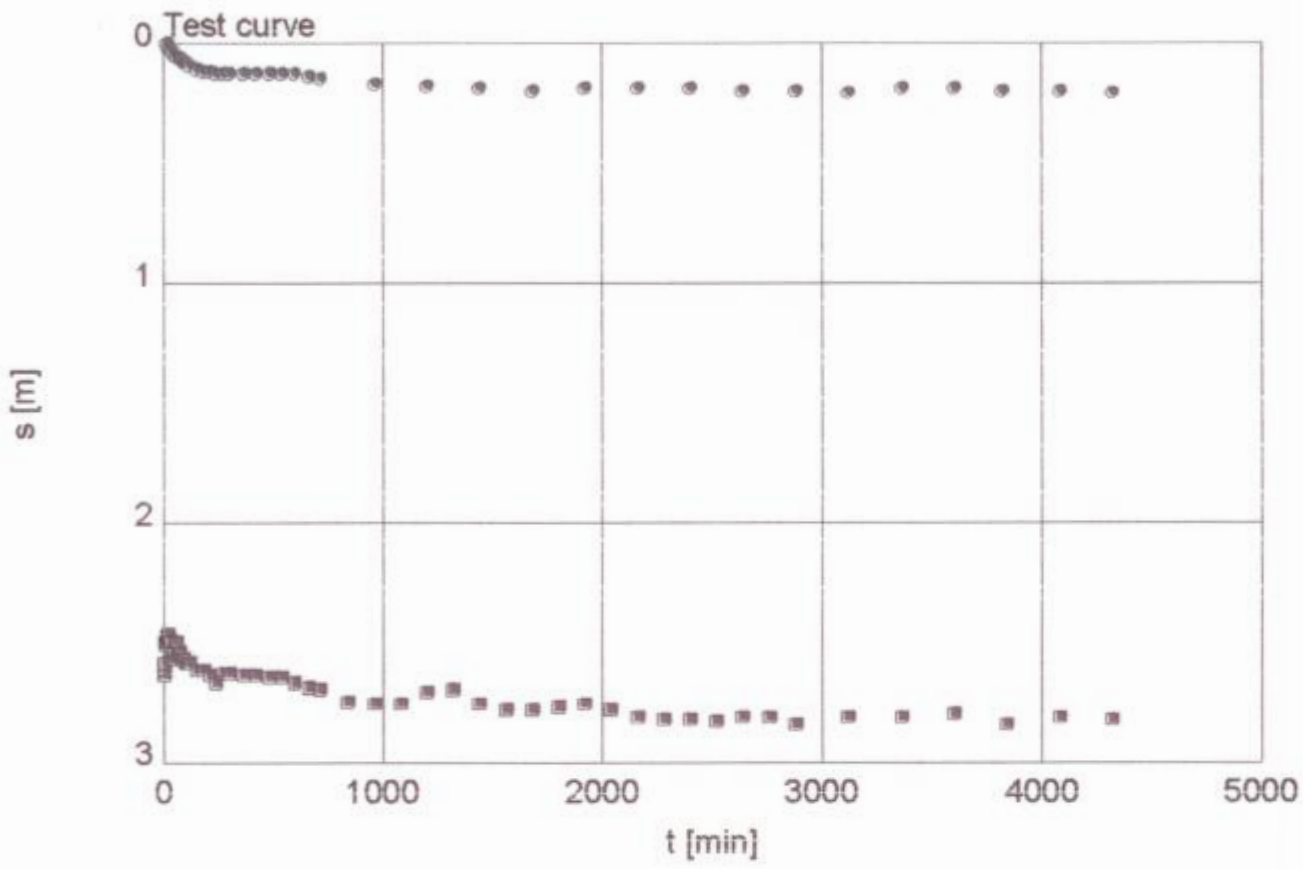
Date 23/10/00	prepared by BIWAC	Annex 5

Groundwater Study in the Stampriet Artesian Basin

Evaluation of Test Pumping Data

Test pumping diagnosis

Pumped well J9_A

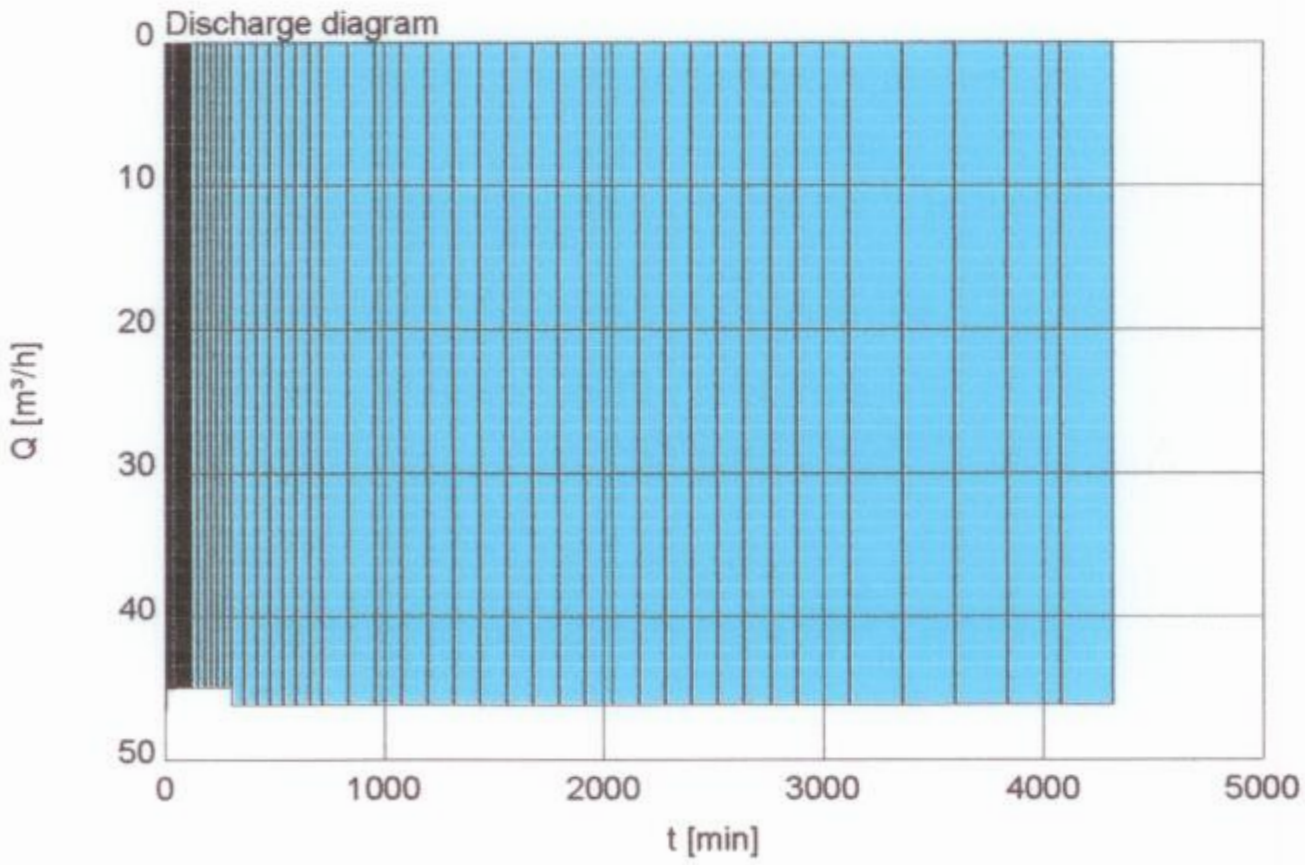


Remarks

Merged draw down data of pumped borehole J9_A and observation borehole WW31759.

Although at 425 m distance there is a clear draw down observed in WW31759 during pumping.

The data of the observation borehole was evaluated for transmissivity and storativity.



Discharge info

Dis.dur.:4320 [min]
tcorr: 4312 [min]

Av.dis.: 46.13 [m³/h]
max.dis.:48.38 [m³/h]
min.dis.:45.02 [m³/h]
Qn: 46.21 [m³/h]

Dis.sum: 3322 [m³]

Reference ▪ J9_A 0.100m • WW31759 425m

Date 23/10/00 prepared by BIWAC Annex 6

7. Water Level Recorder Installation

THE STUDY ON THE GROUNDWATER POTENTIAL EVALUATION AND MANAGEMENT PLAN IN THE SOUTHEAST KALAHARI (STAMPRIET) ARTESIAN BASIN

INSTALLATION OF SEBA FLOATERS

JICA REFERENCE: J 9 A LOCALITY: Klein Swartmodder R 135

WW 39857

1.	**Serial Number of floater**:	4508
2.	**Date installed**:	20/09/00
3.	**Rest Water Level when installed**:	3.72 mbsu
4.	**Distance from stick-up to logger**:	2.0 m
5.	**Distance from logger to water level**:	1.72
6.	**Cut off**:	2.0 m (0.91 + 1.11)